UNCLASSIFIED

AD NUMBER
AD866946
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited. Document partially illegible.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; DEC 1969. Other requests shall be referred to Air Force Foreign Technology Division, TDBDR, Wright-Patterson AFB, OH 45433. Document partially illegible. This document contains export-controlled technical data.**
AUTHORITY
ftd, usaf ltr, 29 oct 1971

THIS PAGE IS UNCLASSIFIED

AD 866946

FTD-HT-23-508-69

FOREIGN TECHNOLOGY DIVISION

TWIN-SHAFT AND DUCTED-FAN AIRCRAFT ENGINES

by

S. Szczeciński

17

EDITED TRANSLATION

TWIN-SHAFT AND DUCTED-FAN AIRCRAFT ENGINES

By: S. Szczeciński

English pages: 14

Source: Biuletyn Informacyjny Instytutu Lotnictwa (Information Bulletin of the Aviation Institute), No. 4, 1968, pp. 32-35.

Translated by: L. Marokus/TDBRS-3

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

 Date 10 Dec. 19 69

TWIN-SHAFT AND DUCTED-FAN AIRCRAFT ENGINES

S. Szczeciński, Docent, Doctor of Engineering

In spite of the considerable structural complexity of twin-shaft engines they are being more and more widely used in aviation, because of their performance and favorable operational properties. Their structural complexity involves a number of difficulties of a design and technological nature. These difficulties are considerably more pronounced in ducted-fan constructions (first of all because of the great diameter dimensions of the high-speed blowers). The important design units of twin-shaft and ducted-fan engines manufactured throughout the world will be briefly described below.

Twin-Shaft Jet Engines

In recent years the constant development of twin-shaft constructions has been observed. After the appearance of the English Bristol Siddeley Olympus engine in the fifties, considering the performance of this engine and its operational properties, it was decided to carry out broad development of the twin-shaft design in many countries of the world. In one of the versions of this engine, a 6-stage low-pressure compressor is driven by a single-stage low-pressure turbine. Also, the compressor rotor as well as the turbine rotor are supported independently (each of them on two bearings) and the rotational moment from the turbine to the compressor rotor is transmitted by the shaft passing within the rotor shaft of the high-pressure compressor. On both ends of this shaft there are splined couplings enabling the

transfer of the rotational moment. The rear bearing of the turbine is inside the output cone of the engine. The reaction forces of this bearing are transmitted to the engine housing by means of ribs situated in the outlet channel. Such external turbine support is highly favorable in view of shaft and bearing loadings, but it requires the assurance of intense rear-bearing cooling at the same time.

The rotors of the high-pressure compressor and the turbine driving it are also independently supported, and the rotational moment is transmitted through a splined articulated coupling. The rotor of the high-pressure turbine is supported by an outrigger. The front bearing of the turbine also transfers transverse reactions from the forward bearing of the low-pressure turbine. Both races of the forward rotor bearing of the low-pressure turbine turn in one direction, at low relative velocities. All the accessories, with the exception of the generator, are driven by the high-pressure rotor. Twin-rotor constructions possess a number of operational advantages, such as, for example, the expansion of the static working range of the engine, easier starting (since the lower power of the starter driving only the high-pressure rotor is sufficient), etc. The generator can be situated in the intake housing of the engine and is driven by a low-pressure rotor. In the compressor housing, between both its rotors there is an automatically controlled air bleeder.

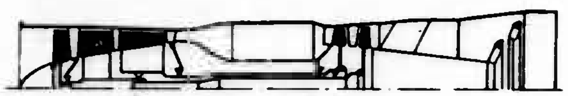

Fig. 1. Structural diagram of a modern Soviet engine.

In Fig. 1 a structural diagram of one of the modern Soviet engines is represented. A single-stage low-pressure turbine drives a 3-stage compressor with the first supersonic stage. A high-pressure turbine drives the 3-stage rotor of the high-pressure compressor. The high degree of compactness and relatively simple construction are noteworthy. The high-pressure rotor (of the compressor and turbine)

was designed to be doubly-supported. The low-pressure compressor is supported by two bearings; the rear bearing is inside the high-pressure compressor rotor and they both spin passively (at low relative velocities). Reactions from the forward bearing of the low-pressure rotor are transmitted by guides situated behind the first compressor stage. The rotor of the low-pressure turbine is supported from the rear of the engine by a bearing placed inside the high-pressure turbine shaft, and from the front it rests in the shaft of the compressor driven by it. The rotational moment and longitudinal and transverse forces are transmitted by a splined coupling. The engine is provided with an afterburner.

Afterburners in modern engines have, as a rule, the possibility of constant regulation of the developed thrust (during constant rpm's of the rotors). Thrust regulation during the operation of the afterburner is attained by regulating the delivery of fuel to the afterburner injectors with simultaneous regulation of the cross section of the exhaust jet cone of the engine.

Housings of modern engines are generally welded together from steel sheets, with the exception of the low-pressure compressor housings, which are made as castings of light alloys. Combustion chamber shields usually compose the support element and aid the remaining support systems of the engine. The basic structural difficulty is to assure proper lubrication and cooling of the bearings located within the high-pressure rotor.

Twin-Shaft Ducted-Fan Engines

For a number of years in countries possessing a highly developed aviation industry, as for example Great Britain, the USSR, and the USA, work in the area of building ducted-fan engines has been going on. Ducted-fan engines are characterized by low unitary fuel consumption within a range of 0.6-0.5 kg/kGh (achieved due to the great delivery of air and a compression on the order of 15-20), with a simultaneously low unitary mass of the engines (amounting to an average of about 0.2 kg/kG).

Rolls-Royce engines are considered to be the leading ones. Engines of this company have very good performance, and, are marked by great reliability and very long service lives, reaching up to several dozens of thousands of working hours.

In the Rolls-Royce Spey engine, a two-stage low-pressure turbine drives a four-stage blower which at the same time constitutes a low-pressure compressor, because a part of the air flows out into an external passage of the engine, and a part is directed to a high-pressure compressor. The high-pressure compressor (a 12-stage one) is driven by a two-stage turbine. The rotor blades of the turbines of all stages possess shelves at their tips. Blades of the high pressure turbine, as well as of the guide wheels and of rotors, are air cooled, which permits a temperature of approximately 1400°K at the turbine inlet. A low-pressure rotor of the Spey engine is supported just as a low-pressure rotor of an Olympus engine. The high-pressure compressor is supported on both sides by bearings fastened in the housing, and the reaction forces of the bearings are transmitted to the housing by means of the compressor guide wheels. The rotor of the high-pressure turbine is supported by an outrigger, on one bearing at the turbine disks; the role of the other support is fulfilled by an articulated splined coupling sitting on the end shaft of a high-pressure compressor rotor.

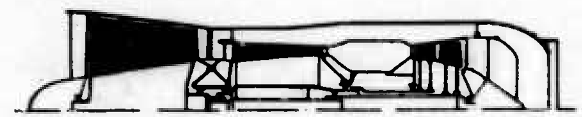

Fig. 2. Structural diagram of a Rolls-Royce Spey engine.

Also worthy of attention is the introduction of air from an external passage into an internal passage behind the turbine with the aid of a number of properly formed intakes, or so-called mixers. The bringing in of air from the external passage and mixing it with combustion gases causes a considerable noise damping of the gases coming out from the engine jet cone. The construction of mixers is similar to the construction of noise damping units already long in

use on a number of jet aircraft operated by commercial aviation.

In the Rolls-Royce Conway engine (R. Co 42), the rotor of a low-pressure compressor consists of a 4-stage fan and separate 3-stage compressor section, working exclusively in the inner channel of the engine. A seven-stage fan/compressor unit is driven by a two-stage low-pressure turbine. The rotor of the 9-stage high-pressure compressor is driven by a one-stage turbine. The method of arranging the rotors of a Conway engine is realized according to the scheme adopted in the Spey engine. Rotor blades of all turbine stages have shelves at their tips. Rotor blades and the guide wheels of the first two stages are air-cooled. The Conway engine also has a row of mixers behind the turbine for air coming from the outer channel with combustion gases of the inner channel. One variety of the engine, shown in the diagram, is also equipped with a thrust reverser consisting of two flaps and grill slots with steering mechanisms. When the reverser is in operation, the flaps close the axial outflow of combustion gases through the engine nozzles, simultaneously opening the grill slots of the reverser.

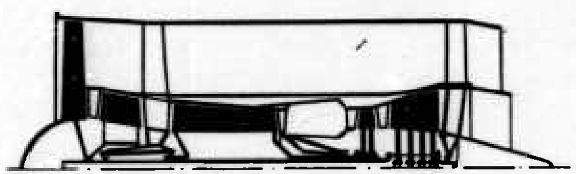

Fig. 3. Structural diagram of a Pratt-Whitney JT-9D engine.

In both Rolls Royce (Spey and Conway) engines, the carrier assembly of the engine is a double-layer construction, consisting of the housing of the inner channel of the engine, connected with a number of guide devices and carrier ribs with the shield of the external channel. Such a construction is characterized by great rigidity and significant lightness of weight.

An increase in thrust may be achieved by using an afterburner in the inner channel, combusting the fuel in the external channel

(thus working like a ramjet engine) or using an afterburner at the outlet of the engine-behind the mixer zone.

In a Pratt-Whitney JT-3D engine, similarly as in a Conway engine, the low-pressure compressor has a divided (two-stage) fan section and a compressor section in the inner channel possessing 6 stages. The fan-compressor unit is driven by a 3-stage low-pressure turbine. The rotor of the high-pressure compressor, having 7 stages, is driven by a single-stage turbine. Noteworthy here is the small number of bearings supporting the rotors of the JT-3D engine. There are only 6 — each of the turbine rotors is supported in bearings. The turbine rotors are supported at the disks on bearings, and their other supports are composed of the articulated splined couplings connecting the turbine shafts with the compressor shafts. Reactions from the bearings are transmitted to the support housing of the engine through the guide wheels of the compressors, turbines and support ribs of the internal cone of the exhaust nozzle.

The carrier housing of the engine is made of almost totally welded steel sheets. The engine described underwent a series of modifications in order to increase its parameters, simplify the manufacturing technology, simplify and facilitate its operation and, finally, reduce manufacturing costs.

The Pratt-Whitney Company has in recent years developed a series of ducted-fan twin-shaft engines. Recently certain data pertaining to a new engine marked by the symbol JT-9D were published. This engine develops a thrust of 18,600 kG, with an air flow intensity through both channels equalling 664 kg/s. Unitary fuel utilization is 0.596 kg/kGh. The engine possesses a relatively freely-rotating, single-stage fan on a common rotor with a 3-stage low-pressure compressor driven by a 4-stage low-pressure turbine. The high-pressure turbine, possessing 11 stages, is driven by a two-stage turbine. The high performance of the engine was achieved, among other things, due to cooling the gases of the turbine blades, as a result of which it is possible to permit the temperature of gases flowing into the turbine to exceed 1400°K. Both rotors of the JT-D9 engine are supported by just 4 bearings, thanks to which the

construction of the entire engine is remarkable in its simplicity and flexibility. Reactions from the bearings are transferred to the carrier housing of the internal channel with the aid of ribs and guide wheels, and to the housing of external channel by ribs situated in the fore and aft sections of the engine. The carrier housings are made as welded ones. A majority of elements of the carrier unit are made in two-layer form, which ensures the required structural rigidity. Special attention has been devoted to reducing the size of the engine, by means of an outrigger fan support and by shortening the combustion chambers.

Because of the considerable length of fan blades (their external diameter amounts to 2430 mm) equalling close to 750 mm, the necessity of their circumferential binding on two different diameters arose, for the purpose of eliminating low-frequency vibrations (of high amplitudes). The unitary mass of the described engine is 0.19 kg/kG, which is a value somewhat lower than the average engines actually produced and operated.

Different in relation to the described engines is the construction of the General Electric CJ-805 engine. In this engine, the 17-stage compressor has a single rotor and is driven by a 3-stage high-pressure turbine. This rotor rests on 3 supports. The fan rotor is seated separately. The number of turbine and fan blades is identical – each of the blades, correspondingly formed, has a turbine part at the hub and fan part at the peak. Such a design is favorable to good turbine cooling, which enables the attainment of greater stresses in the turbo-fan blades in comparison with standard turbine constructions. The construction of the CJ-805 engine is a continuation of the structural form of the Metropolitan Vickers F-3 engine developed at the beginning of the fifties and then dropped.

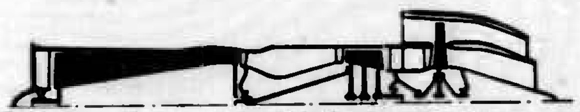

Fig. 4. Structural diagram of General Electric CJ-805 engine.

Twin-Shaft Prop and Helicopter Engines

Dual-shaft systems have come into use most quickly and widely in prop and helicopter engines. No doubt the most favorable form are engines with a free turbine, powering a prop or helicopter rotor exclusively.

In the Bristol-Siddeley Proteus engine, the gas generator consists of a 13-stage axial compressor and a single-stage centrifugal compressor, driven by a 2-stage high-pressure turbine and individual combustion chambers situated around the compressor housing. The air flow scheme adopted for this engine was designed to shorten the engine. The rotor of the 2-stage low-pressure trubine drives the prop by means of a circulation reduction gear. Each of the rotors is set in bearings, and the turbine shafts at the point of coupling with the compressor and reducer possess articulated splined couplings. The relatively long section of the center shaft between the low-pressure turbine and the reductor, is supported by two bearings fastened in the compressor rotor. The greatest relative velocities of the races of these bearings occur during engine operation in the low-throttle range.

Dual-rotor prop engines are characterized by a number of operational advantages, as for example low power needed for starters driving only high-pressure rotors and the capability of engines to rapidly transfer from low throttle to full-power conditions. This is possible due to the fact that the high-pressure rotor operates throughout the entire power range at a practically constant rpm, and the low-pressure turbine – due to the props with adjustable pitch and the high turbine moment, depending mainly upon the temperature of the combustion gases – reaches full-power conditions practically immediately.

To eliminate the possibility of overheating the turbine during constant engine operation, almost all engines powering props or helicopter rotors are equipped with devices for measuring the rotational moment, whose maximum value may restrict the available power of the engine by acting on the fuel system.

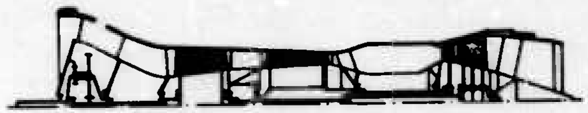

Fig. 5. Structural diagram of a Rolls-Royce Tyne engine.

In the Rolls-Royce Tyne engine a single-stage high-pressure turbine drives a 10-stage compressor. This rotor rests on 3 bearings. A three-stage low-pressure turbine composes the drive for the prop and the 5-stage low-pressure turbine. The rotor of this system is supported on 4 bearings, in which one (the front of the turbine) is fastened in the high-pressure compressor rotor. Connection of the low-pressure turbine rotor with the compressor (and by means of it – with the prop reducer gear) takes place with the aid of an intermediate shaft having splined couplings on both ends.

The diameter sizes of the engine are determined by the engine intake and this is determined by the size of the reducer.

For this reason it is possible to notice the effort to shorten the engine at the expense of increasing the transverse dimensions of the engine determined by the size of the intake. This is attained by using a flow passage for the engine in the return system, as in the BS-Proteus engine, or also a return-flow combustion chamber, as for example in the Lycoming T-56 engine. A single-stage high-pressure turbine drives the compressor rotor here. The whole thing rests in two supports. A single-stage free turbine drives only the prop reducer. The rotor of the free turbine is supported by an outrigger in the housing of the outlet cone of the engine. The rotational moment from this turbine is transmitted to the ruducer with the aid of an intermediate shaft placed with one end in the compressor rotor. The described engine is made in automobile and helicopter versions.

The Allison T-63 engine develops 250 hp at a free turbine velocity of 56,000 rpm's. In this engine, a two-stage low-pressure turbine (free turbine) powers the prop or helicopter rotor, through a reducer whose position depends on engine application. A single-stage

high-pressure turbine drives a 7-stage axial compressor and one-stage centrifugal compressor system. This engine has very small dimensions (intake diameter to the compressor does not exceed 150 mm), which considerably expands its application possibilities.

The design especially developed for powering helicopters is the English Napier Gazelle engine. This engine works in a vertical position – the air intake into the compressor is in the lower part of the engine, and the gas outlet is in the upper part. A two-stage high-pressure turbine drives the 15-stage axial compressor. The generator rotor rests on 3 supports. The role of the forward turbine support is taken care of by a coupling connecting the turbine shaft with the compressor shaft. The lower part of the engine is used to accomodate all the accessory drives. The engine has 6 individual combustion chambers. A single-stage free turbine, made integrally with the shaft, forms the drive of the primary circulation reducer and through this reducer and main helicopter reducer it drives the lift rotor. The discussed engine required the use of a specially developed oil system because of the longitudinal loading characteristic of the bearings and vertical situation of its rotor, and also the placing of the accessory drive gear at the lowest point on the engine.

The primary reduction gear of the engine is fitted with a hydraulic device for measuring the torque moment developed. The reducer is situated in the highest place on the engine.

The engines briefly characterized undergo constant structural, technological and operational evolutions, for the purpose of raising the parameters obtained, simplifying the technology and reducing production costs, and also extending the interrepair periods and reducing the periodic exploitational activities to the absolute minimum. The service life of an RR-Conway engine actually attained is 9000 working hours, where the rotor bearings have been changed after 6000 working hours, exchange of the high pressure turbine guide wheels has occurred after 5500 working hours, etc. After analyzing the necessity of changing the described units or parts when the predetermined time has elapsed interrepair periods are established

for the engine. For military engines these periods normally reach several hundred working hours; for engines of civilian design – several thousand hours. The assurance of a satisfactory service life of the construction, with its total reliability, constitutes one of the basic problems confronting the designers, technologists and users.

Developmental Structural Forms

In connection with the progressing structural development of VTOL aircraft, the modernization and adaptation of propulsion units of conventional aircraft to new problems has come about. A relatively very simple adaptation is the possibility of changing the position of the entire engine from horizontal to vertical. In this case, there are first modifications of the lubrication system. Another type of engine modification is based on the application of properly controlled exhaust nozzles, permitting control of the thrust vector during the horizontal-to-vertical period.

There are whole series of engines, those, for example, produced by the M.A.N. Company with the license of Rolls-Royce, the RB-153 engine, which is a version of the Spey engine used in VTOL aircraft with controlled outflow of combustion gases (downward – under take off and landing conditions, rearward – under normal flying conditions).

Intended exclusively for vertical take off and landing airplanes there arose a series of engine designs and carrier turbofans. The Bristol-Siddeley Company developed a twin-shaft ducted-fan engine in which a single-stage high-pressure turbine drives the rotor of a 6-stage axial compressor. A low-pressure free turbine has mounted on its blades fan blades of the external channel. This turbofan system is analogous to the system in a CJ-805 engine. The fan rotor is situated on the shaft of a high-pressure turbine. For the purpose of axial alleviation of the bearings (also loaded with the weight of the turbofan rotor) a (resilient) relief bushing resting on the forward part of the compressor shaft was used. Engines designed exclusively for work under VTOL conditions are characterized by small dimensions, especially in length and very low unitary masses (even on the order

of 0.06-0.04 kg/kG). The attainment of such high indicators is possible due to the relatively low service life of the unit – these engines work only during take off and landing, and thus the requirements of their service life are considerably lower than those of propulsion engines. The rigid requirements with respect to the lowest possible engine mass have forced designers and technologists to use, for example, artificial materials for the blades (of guide wheels and rotors) and carrier housings of compressors and titanium alloys for turbine rotors.

The development of VTOL aircraft has brought about the creation of special turbofan engines. The turbofan LF-2 of the General Electric Company develops a thrust of 5420 kG with a mass of hardly 239 kg. The ventilator turbine, whose blades are fitted on the external ring of the fan blades, has an external diameter of 1640 mm and close to 360 blades. The fan, which has 36 blades, has a compression of 1.3. The turbine is driven by combustion gases directed from the driving engine, working under take off and landing conditions as a gas generator. In turbofans titanium alloys are used to a large degree, because of their endurance and the low density of the material. In spite of the low rotation velocities of turbofan rotors, amounting on the average to about 4000 rpm's, the inertial forces acting on the individual rotor elements are very great, because of their considerable diameter sizes. Carrier turbofans should be rated as ducted fans, and in a system with a combustion gas generator they are composed of at least two shafts. When the aircraft is in flight, the turbofans are inactive, and their inlets and outlets are closed by a series of movable control bars (flaps acting as shutters).

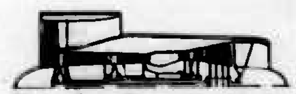

Fig. 6. Structural diagram of a triple-shaft Rolls Royce RB-178 engine.

The economically based prospect of building aircraft of great load capacity (of the class of the Soviet An-22 aircraft), but with somewhat greater flight velocities, involves the necessity of building a jet engine with a thrust of about 20,000 kG. Under just such conditions was the RB-178 engine designed at the Rolls Royce plants. A prototype of that engine was made in May 1967. The construction of the engine was worked out as a ducted-fan. A four-stage low-pressure turbine constitutes the fan drive. The rotor of the 6-stage low-pressure compressor is driven by a single-stage medium-pressure turbine. The high-pressure turbine constitutes the drive of the 6-stage high-pressure compressor. Each of the rotors is placed on two supports with the bearings set in the carrier housing of the engine. Only the bearing of the medium-pressure turbine is situated in the high-pressure turbine shaft. The engine described is said to have a mass of 3510 kg, which gives a unitary mass on the order of 0.17 kg/kG. The fuel consumption foreseen by the designers should be 20-25% lower than the consumption of ducted-fan engines in current operation. The turbine blades are air cooled, using the best cooling technology; however, because of the assumed long service life of the engine the permissible temperature is 80°K less than the temperature permitted on the Conway engine. The RB-178 engine should also be characterized by a low noise level, especially under take off conditions.

The Bristol-Siddeley Pegassus engine was built exclusively as a VTOL aircraft. It is a twin-shaft ducted-fan engine. The air from the external channel (behind a two-stage fan) is directed into two symmetrical outlet channels concluding in guide bars. The combustion gases from the turbine are also conducted by two outlets, arranged symmetrically with respect to the engine. The system adopted will permit dynamic "balancing" of the aircraft during take off and landing, because the thrust vectors are at a considerable distance from the aircraft's center of mass, and their directions and magnitudes are precisely the result of that "balancing."

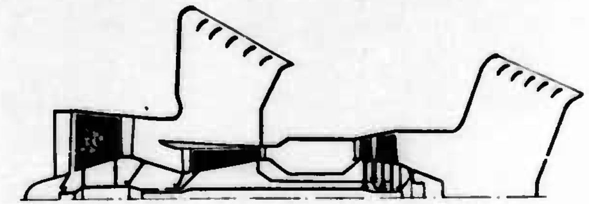

Fig. 7. Structural diagram of a Bristol-Siddeley Pegassus engine for vertical take off and landing engines.

As is evident from the structural designs cited here, the development of their forms is constantly moving forward and its main purpose is to reduce the use of fuel, expand the range of applicability of various types of engines, increase their thrust or power, and, above all, to increase the service life of engines with the most absolute reliability possible under operational conditions.

DATA HANDLING PAGE

01-ACCESSION NO. TT9001927	98-DOCUMENT LOC	39-TOPIC TAGS aircraft engine, twin shaft turbine, jet engine, turbofan engine		
09-TITLE TWIN-SHAFT AND DUCTED FAN AIRCRAFT ENGINES -U-				
47-SUBJECT AREA 01, 21, 13				
42-AUTHOR CO-AUTHORS SZCZECIŃSKI, S.				10-DATE OF INFO -----68
43-SOURCE BIULETYN INFORMACYJNY INSTYTUTU LOTNICTWA (POLISH)				68-DOCUMENT NO. FTD-HT-23-508-69
				69-PROJECT NO. 6040201
63-SECURITY AND DOWNGRADING INFORMATION UNCL. 0			64-CONTROL MARKINGS NONE	97-HEADER CLASN UNCL
76-REEL/FRAME NO. 1890 1885	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR, UK, US	NO. OF PAGES 14
CONTRACT NO.	X REF ACC. NO. 65-	PUBLISHING DATE 94-	TYPE PRODUCT TRANSLATION	REVISION FREQ NONE
STEP NO. 02-PO/0000/68/000/004/0032/0035				

ABSTRACT

(U) This article discusses the development design and use of twin-shaft and ducted-fan aircraft engines in various countries. Specifications of engines cited are given; all specifications of engines mentioned are of western manufacture.